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Publication date:
2018

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Kedwell, K. C., Quist-Jensen, C. A., Jørgensen, M. K., & Christensen, M. L. (2018). *Ammonia transfer in forward osmosis during operation to concentrate digester centrate*. Poster presented at Euromembrane 2018, Valencia, Spain.

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Ammonia transfer in forward osmosis during operation to concentrate digester centrate

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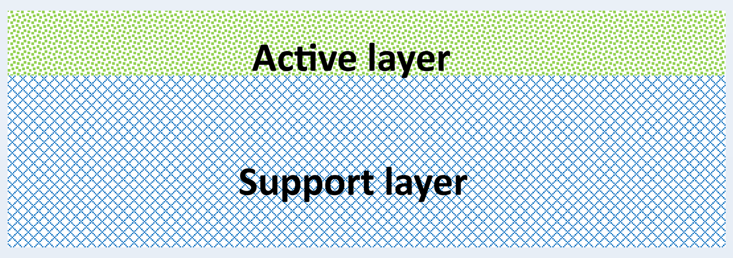
Background

In forward osmosis, water is transported from a feed solution with low osmotic potential to a draw solution with high osmotic potential. Seawater is an inexpensive draw solution if the forward osmosis plant is in the vicinity of the sea, and the seawater can be discharged without treatment, provided there is no contamination from the feed solution. Forward osmosis can be used to concentrate phosphorus from wastewater, but problems have arisen with ammonia contamination of the draw solution. It is important to understand the potential to which ammonia can contaminate the draw solution, and how to reduce it. In this study we evaluate the effect pH has on thin-film composite (TFC) (Porifera, USA) and biomimetic membranes (Aquaporin A/S, Denmark) with regards to ammonia transfer and water flux. Real digester centrate was used as feed solution, while draw solution was seawater or NaCl solution (25-45gL^{-1}).

TFC membranes

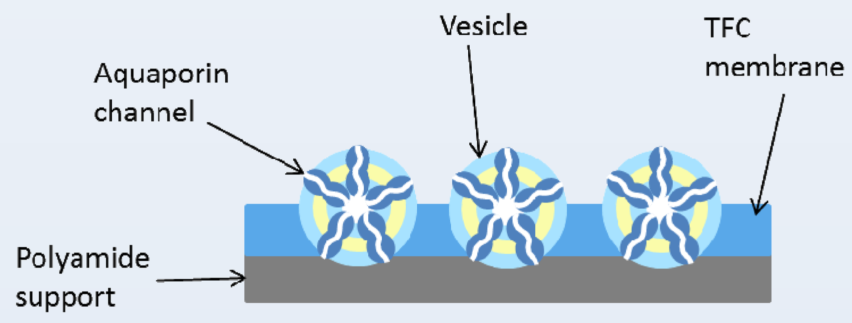
Dopamine anti-fouling polymer layer

Polysulphone or polyethersulphone porous layer



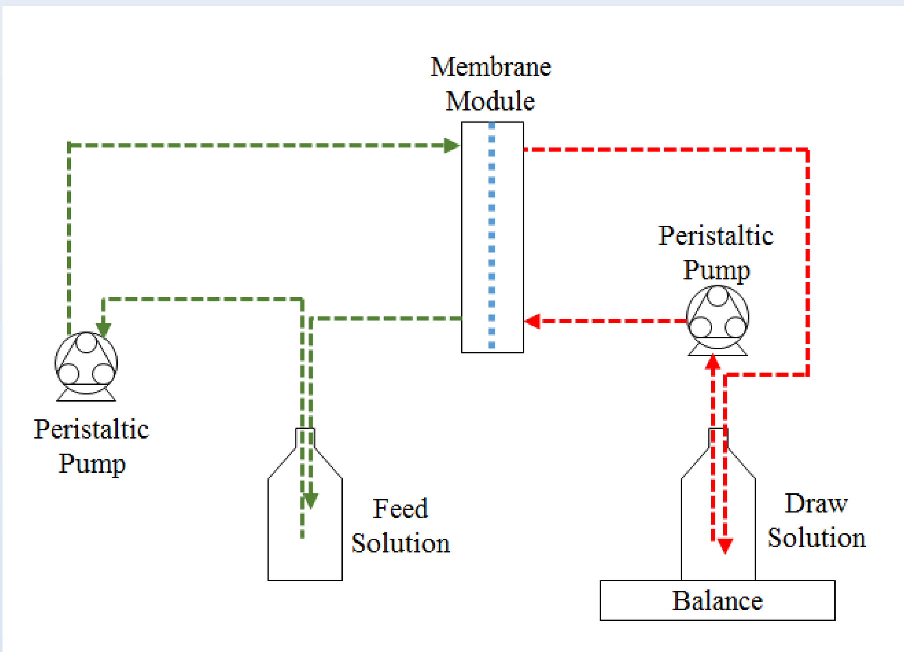
Biomimetic membranes

- Aquaporin protiens can be found in cells
- They are highly selective towards water
- Only the protein channels are permeable



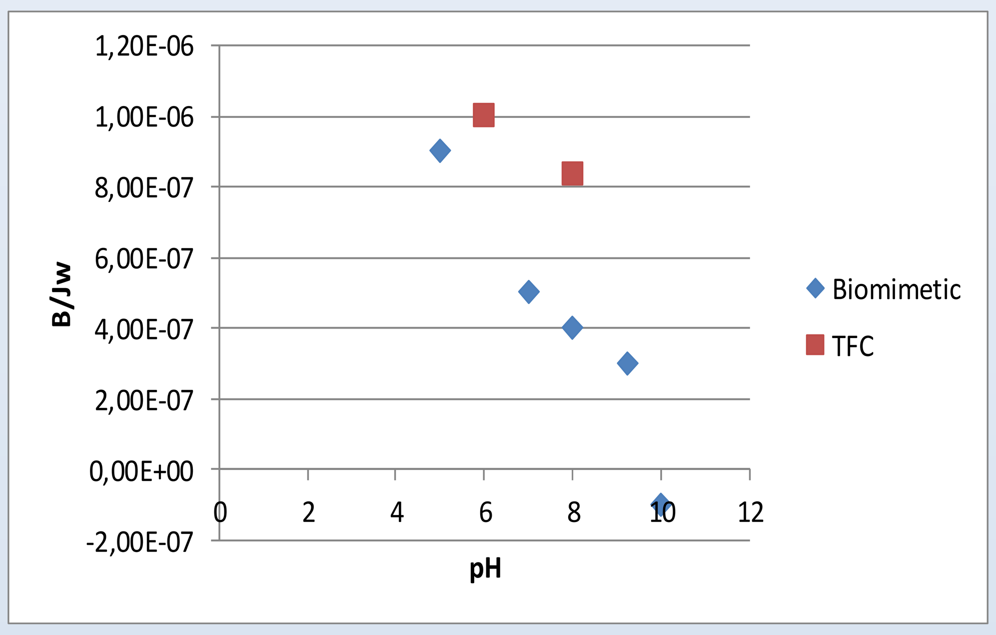
Method

- Feed solution was digester centrate
- Draw solution was seawater or NaCl solution (25-45 gL^{-1})
- 140cm^2 membrane area
- Cross flow configuration



pH and Ammonia Permeability

- B is the ammonia permeability (ms^{-1})
- Convective transport of N reduced at higher pH
- Convective transport of N most pronounced for TFC membranes
- At high pH diffusion of N is more important than the convective transport



Ammonia transport can be explained by the Kadem– Kachalsky equation:

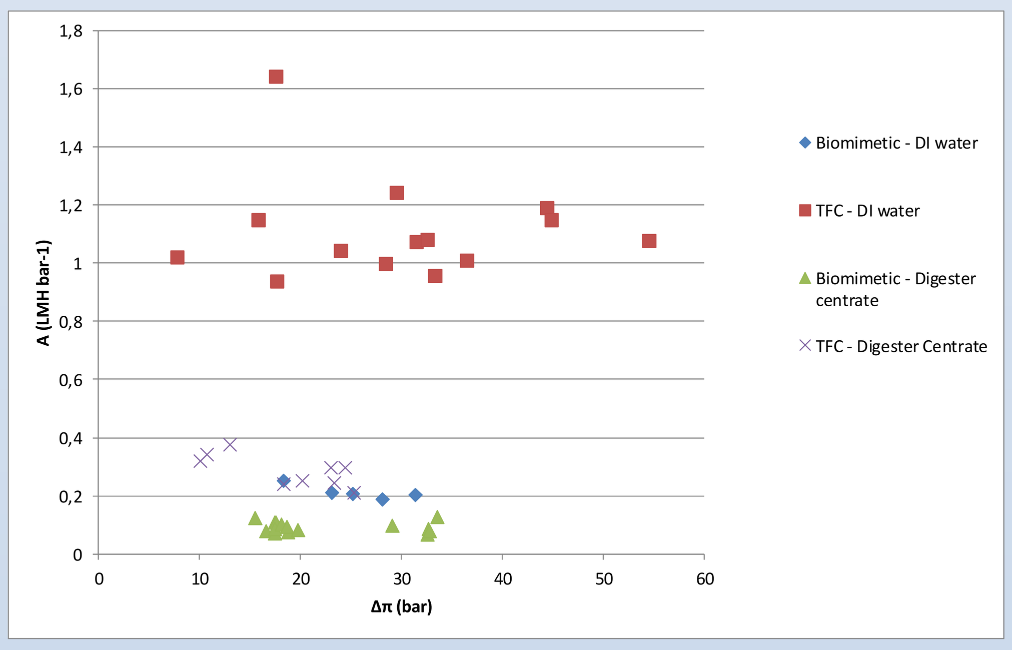
Prominent at low pH

Prominent at high pH

$$J_s = C_{s,av}(1-\sigma)J_w + \Delta\pi\omega$$

Water Flux and Permeability

- Highest permeability for TFC membranes
- Low reduction in water and digester centrate permeability for biometric membrane
- Large difference between the two feed solutions for TFC membranes

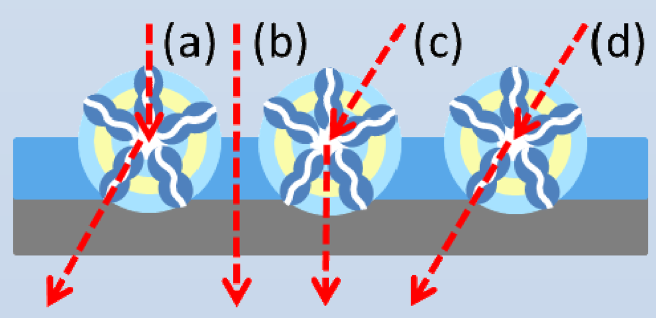


Water permeability using DI water and digester centrate feed solution

Ammonia transfer mechanism in biomimetic membranes

There are four key routes for ammonia to move through the membrane:

(a) - through the aquaporin protien channels
(b) - through the TFC portion of the membrane
(c) - through the vesicle walls
(d) - through a combination of (a) and (c)

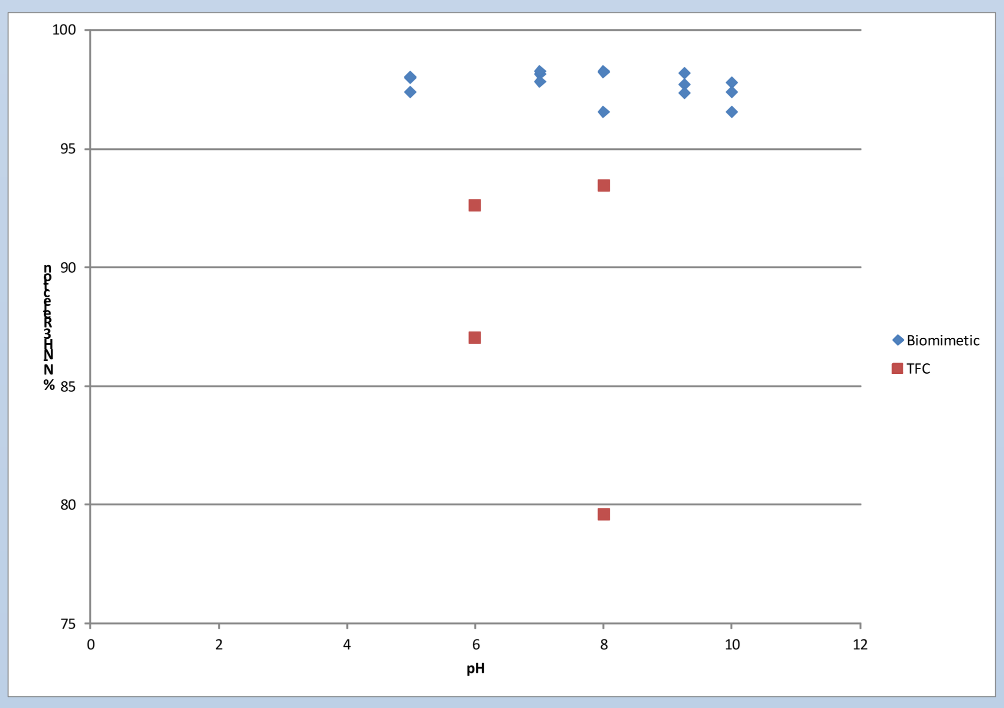


For lower pH ammonia moved via convection, however, with increasing pH convection plays less of a role.

Therefore, at lower pH the transfer of ammonia is via (a), but with increasing pH (b), (c), and (d) play a greater role.

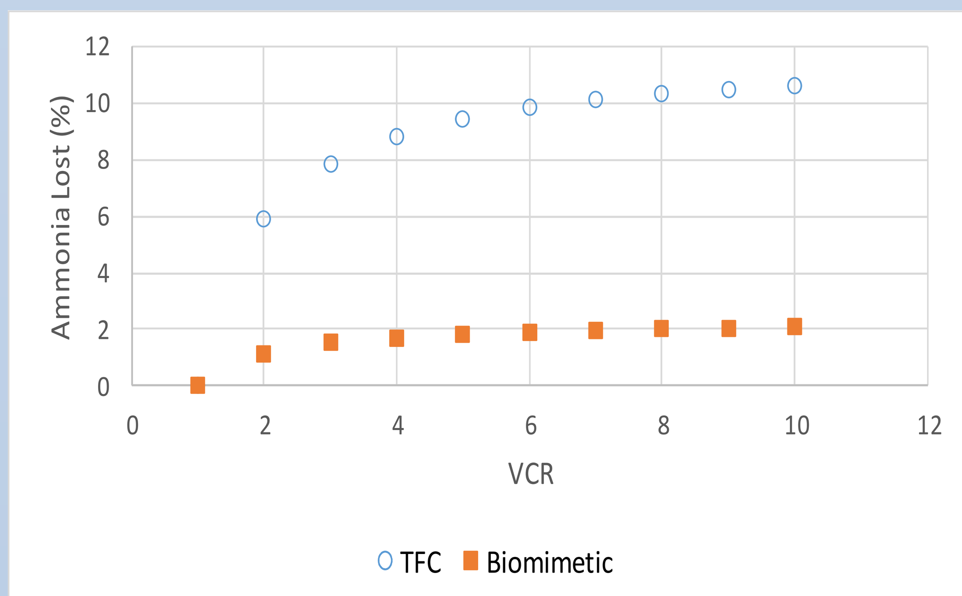
Ammonia Rejection

- Biometric membranes have 97.7% N rejection
- TFC membranes have 88.2% N rejection
- N rejection independent of draw solutions for biomimetic membranes,
- N rejection is reduced at higher draw solution osmotic pressure for TFC membranes
- Difference between two types of membrane is particularly exagerated at pH 8, where a 25gL^{-1} draw solution achieved 93.4% rejection whereas 45gL^{-1} achieved 79.6%



Ammonia Loss

- Volume concentration ratio (VCR) is the final volume divided by the inital volume
- Based off of average rejections of 88.2% (TFC) and 97.7% (biomimetic)



Conclusions

- Ammonia transfer is higher for TFC membranes than biomimetic membranes
- Water permeablity is lower for biomimetic membranes
- Membrane choice will therefore depend on a need for high water flux, or cleaner draw solution
- Ammonia transfer occurs by both convective and diffusive mechanisms
- Convection plays a greater role at lower pH, and diffusion at high pH
- <10% ammonia loss at VCR 6

Acknowledgements Innovation Fund Denmark, Aarhus Vand

References K.C. Kedwell, et al., Forward osmosis with high-performing TFC membranes for concentration of digester centrate prior to phosphorus recovery, Sep. Purif. Technol. 197 (2018) 449–456.